APPARATUS FOR MAKING A GLASS PREFORM BY FLAME HYDROLYSIS

Background of the Invention

This is a continuation-in-part of U.S. Provisional Application No. 60/152,293, filed September 3, 1999.

This invention relates generally to apparatus for making glass preforms by flame hydrolysis and, more particularly, to such apparatus that produce glass preforms at a higher deposition rate and an improved efficiency.

Over the past 20 years, cylindrical glass preforms for use in making optical fibers have been produced by manufacturing synthetic vitreous silica, using a two-step process of soot deposition by flame hydrolysis and sintering. Two major optical fiber production processes that use this flame hydrolysis process are called outside vapor deposition (OVD) and vapor phase axial deposition (VAD). Two other commercial optical fiber production processes, which do not use flame hydrolysis, are called modified chemical vapor deposition (MCVD) and plasma chemical vapor deposition (PCVD).

The basic process of flame hydrolysis was invented more than 50 years ago. It was first commercialized in a one-step deposition process, in which the deposition temperature was maintained sufficiently high for the deposited material to be a dully-dense clear glass. The two-step deposition, in which a porous preform is first deposited at a significantly lower temperature and then sintered into a clear glass, was later commercialized, with the advent of optical fibers. This two-step process also has been adapted to other applications, because it permits the production of materials incorporating fewer hydroxyl ions.

In such flame hydrolysis processes, silicon-containing precursor materials of various kinds are vaporized and then fed with reactant gases to a burner that produces an oxy-hydrogen or oxy-gas flame within a deposition chamber. The reaction within the flame produces sub-micron soot particles of silica that are collected along the length of a cylindrical deposition surface defined on a cylindrical mandrel. Relative axial motion is provided between the burner and the deposition surface, while the mandrel is rotated. Soot particles collect on the deposition surface by a phenomenon called thermophoresis, in which particles present in a thermal gradient are caused to move towards the colder surface.

Deposition rate and soot collection efficiency are two key parameters affecting process economy. These parameters are controlled in large part by the configurations of the burner and the deposition chamber. In designing these components, it must be recognized that the deposition can occur over a range of shapes, one of which being a cylindrical rod shape. In cylindrical deposition, the starting mandrel diameter can be less than 1 cm and the final diameter can be greater than 40 cm. In addition, it is important to maintain the temperature of the deposition surface sufficiently high to provide a high soot density and prevent cracking, but not so high as to cause partial sintering, which can form bubbles in the sintered glass. The diameter of the deposited material must be uniform, and the ends of the deposited material must be maintained at a temperature sufficiently high to prevent flaking.

The efficiency of the flame hydrolysis process described briefly above depends on many factors, including the choice of reactants, the choice of flame gases, the choice of the starting diameter and final diameter of the deposited material, the design of the burner, and the design of the deposition chamber.

Numerous burner configurations have been developed over the years for use in the optical fiber industry, the most common being referred to as concentric tube burners and aperture burners. Schematic diagrams of such burners are shown in FIGS. 1 and 2, respectively. Another common type of burner, used in the fused silica products industry, combines certain characteristics of both concentric tube burners and aperture burners. A schematic diagram of the face of such a burner is shown in FIG. 3. These burners use oxy-hydrogen or oxy-gas flames, and they function as surface mixed and premixed burners. These burners typically are constructed of fused silica glass or metals, such as aluminum or stainless steel.

The basic burner configurations of FIGS. 1-3 have the common design feature of circular symmetry. In each case, the reacting chemicals are ejected in a stream from the center of the burner, and a shield gas stream encircles the chemical stream, to shield it from the surrounding flame. In this manner, the reaction occurs away from the burner face, which in turn prevents an undesired build-up of reactants on the burner surface, which could adversely affect performance. These burners all are configured such that their faces, from which the gases and chemicals are ejected, are substantially planar. The burner configurations differ from each other in several ways, including their thermal profile, the Reynolds number at which each operates optimally, the distance from the face at which the reaction occurs, and the length of the flame. Those skilled in the art will recognize the significance of these parameters in the deposition process.

Other burner configurations, not depicted in the drawings, include: 1) ribbon burners having multiple chemical flows ports and non-circular flame configurations, 2) offset chemical tube burners, and 3) multiple flame burners configured to provide flames that exit the burner at different planes.

Most optical fiber preform producers use reactants that are chlorides of glass-forming materials, and one of the reaction products is hydrochloric acid. In addition, not all of the glass-forming oxide particles, or soot, are collected on the deposition surface. Consequently, the deposition chamber needs to be closed, and the exhaust needs to be treated to neutralize the acid and to remove the undeposited soot particles.

FIG. 4 depicts a simple form of a deposition chamber for depositing a cylindrical shape. The depicted chamber incorporates a stationary burner located on one side of the chamber and an exhaust port on the opposite side. A chuck assembly holds the mandrel, on which soot is deposited to form a rod, in a vertical orientation. A motor located above the chuck assembly rotates the mandrel, and the entire mechanism is mounted on a traverse mechanism that allows the entire length of the rod to be moved up and down across the flame and the stream of soot particles produced by the burner. A layer of soot is deposited onto the rod each time the rod traverses the burner flame, and the process continues until the desired amount of glass has been deposited.

In alternative designs, the rod can have a horizontal orientation, and the burner can traverse along the stationary but rotating rod to deposit soot, layer by layer. In such designs, the exhaust port can be stationary or can traverse in synchronism with the burner. The burner can be oriented either horizontally or vertically.

One limitation of the burners described briefly above is that they all must be configured to provide three distinct functions: (1) generating soot, (2) providing a thermophoretic-driving force required for efficiently depositing the soot on the substrate, and (3) supplying heat to control the deposited soot density. This has limited the deposition rate that can be achieved using just a single burner. In

addition, systems incorporating multiple burners are considered to require unduly complex control schemes and a much higher degree of precision in burner design.

The use of just a single burner for both generating soot and providing a thermophoretic-driving force can limit the size of the deposition surface that can be produced efficiently. A thermophoretic driving force exists only if the soot stream is confined between the flame envelope and the deposition surface. Consequently, the flame length must be sufficient to completely wrap around the deposition substrate, as shown in FIG. 5.

In the thermophoretic deposition onto a cylindrical rod, the deposition rate for a given burner should generally be proportional to the rod's diameter. Thus, higher average deposition rates are achieved for preforms having larger diameters. As shown in FIG. 6, for deposition surface diameters in the range of about 5 to 12 cm, the deposition rates of conventional burners increase generally linearly with diameter, as is theoretically predicted. However, the deposition rates of such burners fail to continue increasing after the rod diameter has reached a specific value, e.g., about 12 cm.

One reason for this lack of linearity is that, for large rod diameters, the flame length of the burner is inadequate to provide a thermophoretic-driving force around the entire circumference of the rod. Also, as the substrate diameter increases, the linear surface velocity increases correspondingly, as does the rate at which heat is lost from the substrate. Consequently, the deposition temperature can be maintained only by providing additional heat or a higher gas flow. Further, increasing the flame length requires increasing the amount of reactant fed to the burner, but this increases the turbulence in the deposition zone, which decreases deposition efficiency and reduces the deposition rate. Turbulence can be reduced by withdrawing the burner from the substrate as the substrate grows, but an inadequate

flame length can reduce the amount of heat transferred from the flame to the substrate, making it harder to maintain soot density. The overall soot collection efficiency of the best compromise design is only about 50%.

Turbulence in the deposition zone can be controlled if the flame is oriented so as to impinge on the deposition surface at an angle along the rotation axis. This can improve the soot collection efficiency to about 70%, but it restricts the number of burners to only one. In addition, the flame length of this single burner can limit preform diameter.

One way to provide increased flame length is to use a multi-flame burner, in which two or more flames are produced concentrically around the chemical tube. The first flame originates at the exit plane of the chemicals from the burner, and the other flames originate closer to the deposition target. One problem with this design is that the widths of the flames increases, which creates a longer path for soot particles to travel before they deposit. The increase in flame length also is limited.

Another approach is to use multiple burners, separated axially along the target rod, with soot streams being directed perpendicular to the deposition surface. In this approach, the axial separation of the burners can increase the size of the ends of the deposition surface subject to nonuniformity. The effective collection efficiency of usable soot drops to only about 30%.

Multiple-burner machines with burners placed circumferentially around the target rod generally do not increase the deposition rate, because the flame from the first burner effectively prevents soot steams from the remaining burners from depositing on the deposition surface. To overcome the fundamental

limitations of existing burners, very complicated multiple-burner deposition machines have had to be developed.

It should be appreciated that there is a need for an improved deposition apparatus for producing glass preforms by flame hydrolysis having improved efficiency. The present invention fulfills this need and provides further related advantages.

Summary of the Invention

The present invention resides in a deposition apparatus for making a glass preform by flame hydrolysis, with an improved efficiency. The apparatus includes a support mandrel mounted within a deposition chamber, for rotation about a longitudinal axis, and a main deposition burner configured to direct a stream of soot-forming reactants and a stream of flame gases toward the support mandrel, so as to form by flame hydrolysis a glass preform on the mandrel. One or more auxiliary burners configured to introduce a stream of flame gases, but no stream of soot-forming reactants, toward the glass preform, to heat portions of the preform not fully heated by the stream of flame gases directed by the main deposition burner. A controller is configured to controllably operate the one or more auxiliary burners after the glass preform formed on the support mandrel has reached a predetermined size. The auxiliary burners can be located on opposite sides of the main deposition burner, spaced circumferentially around the support mandrel.

In a more detailed feature of the invention, the main deposition burner is configured to direct a stream of soot-forming reactants quasi-tangentially toward the glass preform being formed on the support mandrel. In addition, the apparatus can further include a mount configured to withdraw the main deposition burner from the glass preform as the preform grows in size. Both of these features can

reduce turbulence in the stream of soot-forming reactants at the site of the preform, and thereby improve the soot collection efficiency.

The main deposition burner includes a reactant port, aligned with a central axis, for forming the stream of soot-forming reactants, and it further includes a plurality of flame ports, arranged concentrically around the reactant port, for forming the flame concentrically around the stream of soot-forming reactants. The main deposition burner can further include a first plurality of shield gas ports, arranged concentrically around the reactant port, between the reactant port and the plurality of flame ports, for forming an inner shield gas stream between the stream of soot-forming reactants and the flame, and a second plurality of shield gas ports, arranged concentrically around the reactant port, radially outward of the plurality of flame ports, for forming an outer shield gas stream radially outward of the flame.

The plurality of flame ports can be configured to direct the flame obliquely inwardly toward the main deposition burner's central axis. These flame ports can be asymmetrically configured, such that the flame is oriented obliquely inwardly toward the main deposition burner's central axis along one transverse axis, but is oriented substantially parallel with such central axis along an orthogonal transverse axis.

In one form of the invention, the main deposition burner can include a central reactant port, aligned with the burner's central axis, for forming a central stream of soot-forming reactants that impinges substantially radially on the glass preform being formed on the support mandrel, and can further include a pair of supplemental reactant ports located on opposite sides of the central reactant port, for forming supplemental streams of soot-forming reactants that impinge quasi-tangentially on the glass preform. A valve can control the delivery of reactant gases

to the central port and to the pair of supplemental ports, according to the size of the glass preform being formed on the support mandrel.

The main deposition burner can be configured to burn either a mixture of oxygen and natural gas or a mixture of oxygen and hydrogen.

Other features and advantages of the present invention should become apparent from the following description of the preferred embodiments, taken in conjunction with the accompanying drawings, which disclose, by way of example, the principles of the invention.

Brief Description of the Drawings

FIG. 1 is a simplified perspective view of a prior art concentric tube burner .

FIG. 2 is a simplified perspective view of a prior art aperture burner.

FIG. 3 is a simplified view of the face of a prior art combination aperture/concentric tube burner.

FIG. 4 is a schematic diagram of a prior art deposition system for producing a cylindrical glass preform by flame hydrolysis.

FIG. 5 is an end view of the prior art deposition system of FIG. 4, showing the flame wrapped around the cylindrical preform.

FIG. 6 is a graph depicting the relationship between target diameter and deposition rate for a typical prior art single-burner deposition system.

FIG. 7 is a simplified schematic drawing of one embodiment of a deposition system for producing a cylindrical glass preform by flame hydrolysis in accordance with the invention.

FIG. 8 is a view of the face of a first embodiment of a burner assembly in accordance with the invention.

FIG. 9 is a cross-sectional view of the burner assembly of FIG. 8, taken substantially in the direction of the arrows 9-9 in FIG. 8.

FIG. 10 is a view of the face of a second embodiment of a burner assembly in accordance with the invention, this embodiment differing from the embodiment of FIGS. 8 and 9 in that the flame is directed inwardly toward the burner's central axis.

FIG. 11 is a cross-sectional view of the burner assembly of FIG. 10, taken substantially in the direction of the arrows 11-11 in FIG. 10.

FIG. 12 is a view of the face of a third embodiment of a burner assembly in accordance with the invention, this embodiment differing from the embodiments of FIGS. 8-11 in that the flame is directed inwardly toward the burner's central axis only in the direction along the axis of the target rod.

FIG. 13 is a cross-sectional view of the burner assembly of FIG. 12, taken substantially in the direction of the arrows 13-13 in FIG. 12.

FIG. 14 is a cross-sectional view of the burner assembly of FIG. 12, taken substantially in the direction of the arrows 14-14 in FIG. 12.

FIG. 15 is a view of the face of a fourth embodiment of a burner assembly in accordance with the invention.

FIG. 16 is a view of the face of a fifth embodiment of a burner assembly in accordance with the invention.

Description of the Preferred Embodiments

With reference now to the illustrative drawings, and particularly to FIG. 7, there is shown a system in accordance with the invention, for producing a cylindrical glass preform 20 by flame hydrolysis. The preform is formed on a starting mandrel or rod 22, which is mounted for rotation within a deposition chamber 24. A main deposition burner 26 directs both a stream of soot particles 28 and an encircling flame 30 toward the rotating rod. By the phenomenon of thermophoresis, the soot particles are caused to move away from the flame and toward the rotating rod, for deposition on the rod as a thin layer. The main burner is moved axially relative to the rotating rod by a carriage assembly (not shown in the drawings). The glass preform thereby is built up, layer by layer, into a cylindrical shape.

Although the rod 22 is depicted as rotating about a horizontal axis, and the main deposition burner 26 is depicted as directing the soot stream 28 upwardly toward the rod, it will be appreciated that alternative orientations also could be used. Undeposited soot particles and the exhaust from the flame 30 exit the deposition chamber 24 via an exhaust port 32 located on the side of the rod opposite the main burner.

As the preform 20 grows in diameter, layer by layer, it eventually will reach a diameter where the length of the flame 30 from the main deposition burner

24 is inadequate to wrap around the preform's entire circumference. This could adversely affect the deposition efficiency, by limiting the thermophoresis effect for portions of the soot stream 28 not confined by the flame. To avoid this problem, the system further incorporates additional pairs of auxiliary burners 34a,b and 36a,b, spaced circumferentially around the rod 22 and preform 20, on opposite sides of the main burner. These auxiliary burners are controlled so as to direct flames 38 toward the preform after the preform has grown to a predetermined size.

The auxiliary flames 38 ensure that the substrate's entire circumference is enveloped by flame, even as the preform substrate 20 approaches its final diameter. In addition, the auxiliary flames impinge obliquely on the preform, and the velocities of the flames are controlled, so as to minimize turbulence on the preform's deposition surface. It will be appreciated that additional (or fewer) auxiliary burners alternatively could be used, and the relative positioning of the auxiliary burners could be modified, depending on various factors, including the lengths of the flames and the preform's anticipated final diameter.

With reference now to FIGS. 8 and 9, the main deposition burner 26 incorporates three reactant feed tubes 40a,b,c, which generate three soot streams 42a,b,c. The center feed tube 40b is oriented radially relative to the axis of the rotating rod 22 and preform 20. When the preform is relatively small in diameter, most of the reactant is fed through the center tube 40b for the soot stream 42b. However, as the preform diameter grows, most of the chemicals are fed through the lateral feed tubes 40a,c. A valve 44 controls the delivery of the reactants to the feed tubes. The lateral soot streams 42a,c produced by the lateral feed tubes impinge quasi-tangentially on the deposition substrate, to reduce turbulence at the preform's deposition surface.

The main deposition burner 26 produces the flame 30 by directing a mixture of oxygen and natural gas or oxygen and hydrogen into a ring-shaped gas chamber 46 concentric with the center of the feed tubes 40a,b,c. The gas mixture exits the gas chamber via a number of ports 48 forming a ring around the feed tubes. Concentric with the gas chamber are a ring-shaped inner shield chamber 50 and a ring-shaped outer shield chamber 52, which receive a nitrogen shield gas and direct this shield gas via exit ports 54 and 56, respectively. This forms an inner ring-shaped shield gas stream, located between the reactant streams 42a,b,c and the flame, and an outer ring-shaped shield gas stream, located radially outward of the flame. The ports that form these two shield gas streams are oriented such that the streams follow non-convergent paths that are substantially parallel with the burner's central axis.

To further reduce turbulence at the site of the deposition surface on the preform 20, the main deposition burner 26 is mounted on a carriage 58 that permits the burner to be withdrawn from the preform as the preform's diameter continues to grow. It should be understood that if the starting rod diameter is sufficiently large, the central feed tube 40b could be eliminated, leaving just the two lateral feed tubes 40a,c for producing two quasi-tangential soot streams.

FIGS. 10 and 11 depict an alternative embodiment of a main deposition burner 26' in accordance with the invention. This burner differs from the burner 26 of FIGS. 8 and 9 in that ports 48' that produce the flame 30' and the ports 56' that produce the outer ring-shaped shield gas stream are oriented such that the two streams converge toward the central soot stream 42b. This configuration provides a flame of reduced width. It is particularly useful as part of a deposition machine having multiple deposition burners spaced axially along the rotating rod and deposition substrate.

FIGS. 12-14 depict another alternative embodiment of a main deposition burner 26" in accordance with the invention. This burner differs from the burner 26 of FIGS. 8 and 9 and the burner 26' of FIGS. 10-11, in that it is asymmetric. Ports 48" for the flame gases are oriented such that the flame 30" converges toward the burner's soot stream 42b only along one of its two orthogonal axes, i.e., the axis depicted in FIG. 13. Ordinarily, this axis would be aligned parallel with the axis of the rotating rod and deposition substrate, thereby reducing flame width along that axis. The flame does not converge along the orthogonal axis (FIG. 14), but instead is oriented substantially perpendicular to the burner's face. This facilitates a quasi-tangential flow along the deposition substrate's circumference. This burner configuration is particularly suitable for use in depositing soot onto substrates having a large diameter.

The auxiliary burners 34a,b and 36a,b can have a configuration that is the same as that of the concentric tube burner or aperture burner of prior art, but without the central chemical stream.

For burners receiving an oxygen/gas mixture, the preferred burner design is the aperture burner 26 of FIGS. 8 and 9 and it formed of a suitable metallic material. Surface-mixed burners also are suitable, and all of the features of this invention can be designed into surface-mixed burners. For burners receiving an oxygen/hydrogen mixture, the preferred burner design is a concentric tube burner constructed of glass tubes. Those skilled in the art are readily capable of designing a suitable concentric tube burner having a design according to this invention.

The invention will be better understood from the following more detailed disclosure of three exemplary embodiments of deposition machines in accordance with the invention.

EXAMPLE 1

FIG. 15 depicts the face of a fourth preferred embodiment of a main deposition burner 60 in accordance with the invention. Like the burner 26" of FIGS. 12-14, the face of this burner is asymmetric; however, unlike the burner of FIGS. 12-14, this burner 60 does not incorporate ports for forming an outer shield gas stream. The burner is of the chemical tube aperture type, and it is particularly suited for burning an oxygen/natural gas premix. The parameters set forth below are considered suitable for a deposition machine incorporating the burner 60 of FIG. 15.

Deposition Burner Configuration:

Chemical tubes:	ID of central tube: 6 mm
	OD of central tube: 8 mm
	ID of quasi-tangential tubes: 8mm
	OD of quasi-tangential tubes: 10 mm
	Angle of quasi-tangential tubes: 10°
Inner shield:	Asymmetric chamber: Minor axis – 15 mm
	Major axis – 35 mm
	Number of apertures: 10 to 20
	Aperture ID – 1 mm
Premixed oxygen/gas:	Axial taper angle: 15°
	Minor axis width: 35 mm
	Major axis width: 55 mm
	Number of apertures rings: 2
	Number of apertures: 30 to 90
Outer shield:	Not recommended, so not specified
Gas flow:	Flame: Oxygen/natural gas

Inner shield: Argon

Chemical tube: oxygen/silicon tetrachloride ($SiCl_4$) vapor

Flow velocities: Oxygen/natural gas: 40 slpm (constant)

Inner shield: same as oxygen/natural gas

$SiCl_4$: 1gm/m first pass

10 to 20 gm/m ramp, to 5 cm diameter

20 to 120 gm/m ramp, to final diameter

Oxygen in chemical tube: 1 slpm (optional)

Deposition Chamber and Rod:

Rod rotation rate: 60 rpm

Flame orientation: Vertically upward

Material of construction: 316 Stainless Steel

Burner shield: Silica tube protruding 50 mm upwardly from the burner face

Burner traverse: 30 cm/m

Burner to deposition surface distance: 15 cm, start to 5 cm diameter

Ramp to 20 cm, for 5 cm diameter to end

Auxiliary burners: Number of burners: 2

Orientation: vertically upward

Distance from starting rod surface: 15 cm

Distance between burner axes: 10 cm

Flame width: 25 mm (approximately)

Flows: oxygen/natural gas

Flow rate: as needed, for density control

The flow of the central chemical stream is likely to exceed a Reynolds number of 2000, and the flow at the face of the burner 60 might be turbulent. The velocity of this stream will decrease as it flows toward the deposition surface, and the process will remain efficient so long as the stream becomes laminar by the time it reaches the surface. The auxiliary burners are operated only after the diameter of the preform has reached a predetermined value, and the heat they generate should be gradually increased as the preform diameter increases.

Example 2

FIG. 16 depicts the face of a fifth preferred embodiment of a main deposition burner 62 in accordance with the invention. The burner is asymmetric, like the burner 60 of FIG. 15, but it is of the quartz tube type. It is particularly suited for burning an oxygen/hydrogen mixture. The parameters set forth below are considered suitable for a deposition machine incorporating the burner 62 of FIG. 16.

Deposition Burner Configuration:

Chemical tubes:	ID of central tube: 6 mm
	OD of central tube: 8 mm
	ID of quasi-tangential tubes: 8mm
	OD of quasi-tangential tubes: 10 mm
	Angle of quasi-tangential tubes: 10°
Inner shield:	Asymmetric chamber
	Minor axis ID: 12 mm
	Wall thickness: 1 mm

	Major axis: 2 mm larger than length of tube assembly
Flame hydrogen tube:	Axial taper angle: 15°
	Minor axis with 1-3 mm gap
	Wall thickness: 1 mm
	Major axis with 1-3 mm gap
	Wall thickness: 1 mm
Flame oxygen tube:	Axial taper angle: 15°
	Minor axis with 1-3 mm gap
	Wall thickness: 1 mm
	Major axis with 1-3 mm gap
	Wall thickness: 1 mm
	Reynolds No.: 1500
Gas flows:	Flame hydrogen: 60 slpm
	Flame oxygen: 40 slpm (constant)
	Inner shield: as required, to prevent burner build-up
	$SiCl_4$: 1gm/m first pass
	10 to 20 gm/m ramp, to 5 cm diameter
	20 to 120 gm/m ramp, to final diameter
	Oxygen in chemical tube: 1 slpm (optional)

Deposition Chamber and Rod:

Rod rotation rate:	60 rpm
Flame orientation:	Vertically upward
Material of construction:	Fused silica
Burner shield:	Silica tube protruding 50 mm upwardly from the burner face

Burner traverse:	30 cm/m
Burner to deposition surface distance:	15 cm, start to 5 cm diameter Ramp to 20 cm, for 5 cm diameter to end
Auxiliary burners:	Number of burners: 2 Orientation: vertically upward Distance from starting rod surface: 15 cm Distance between burner axes: 10 cm Flame width: 25 mm (approximately) Flows: flame hydrogen and oxygen Flow rate: as needed, for density control

The flow of the central chemical stream is likely to exceed a Reynolds number of 2000, and the flow at the face of the burner 62 might be turbulent. The velocity of this stream will decrease as it flows toward the deposition surface, and the process will remain efficient so long as the stream becomes laminar by the time it reaches the surface. The auxiliary burners are operated only after the diameter of the preform has reached a predetermined value, and the heat they generate should be gradually increased as the preform diameter increases.

Example 3

Yet another preferred embodiment of a deposition system in accordance with the invention uses a main deposition burner that is symmetric, like the burner 26 of FIGS. 8 and 9. It is of the quartz tube type, with only two chemical tubes, each configured to produce a reactant stream having an oblique incidence on the target rod. The burner is particularly suited for burning an oxygen/hydrogen mixture. Its purpose is to clad vapor phase axial deposition

(VAD) cores on line. The parameters set forth below are considered suitable for a deposition machine incorporating this burner.

Deposition Burner Configuration:

Chemical tubes:	ID of quasi-tangential tubes: 6 mm
	OD of quasi-tangential tubes: 8 mm
	Angle of quasi-tangential tubes: 5°
Inner shield:	Chamber diameter: 25 mm
Flame hydrogen:	Cylindrical, diameter adjusted for proper velocity
Flame oxygen:	Cylindrical, diameter adjusted for proper velocity
Outer shield:	Not recommended, so not specified
Gas flows:	Flame hydrogen: 60 slpm
	Flame oxygen: 30 slpm
	Inner shield: as required, to prevent burner build-up
	$SiCl_4$: adjusted for desired t/a ratio

Deposition Chamber and Rod:

Rod rotation rate:	As practiced in conventional VAD
Flame orientation:	Inclined 15° upward from horizontal
Material of construction:	Fused silica
Burner shield:	Fused silica protruding at least 50 mm from burner face
Burner to deposition surface distance:	15 cm

Auxiliary burners:	Number of burners: 2
	Orientation: inclined 15° upward
	Distance from starting rod surface: 15 cm
	Distance between burner axes: 10 cm
	Flame width: 25 mm (approximately)
	Flows: flame hydrogen and oxygen
	Flow rate: as needed, for density control

It should be appreciated from the foregoing description that the present invention provides an improved apparatus, and related method, for making a glass preform by flame hydrolysis. The apparatus includes a main deposition burner configured to direct a stream of soot-forming reactants and a stream of flame gases into a deposition chamber, in a direction toward a rotating support mandrel, so as to form by flame hydrolysis a glass preform on the mandrel. In addition, a pair of auxiliary burners is included, for introducing streams of flame gases, but no streams of soot-forming reactants, toward the glass preform, from opposite lateral sides of the main deposition burner; to provide additional heat when the preform has reached a predetermined size, thereby improving efficiency.

Although the invention has been described in detail with reference only to the preferred embodiments, those skilled in the art will appreciate that various modifications can be made without departing from the invention. Accordingly, the invention is to be defined only by the following claims.